

Multidisciplinary Analysis of a Hypersonic Engine

ISTAR Flowpath

**Ambady Suresh
Mark Stewart**



Computing and Interdisciplinary Systems Office
Glenn Research Center

2002 CISO Review

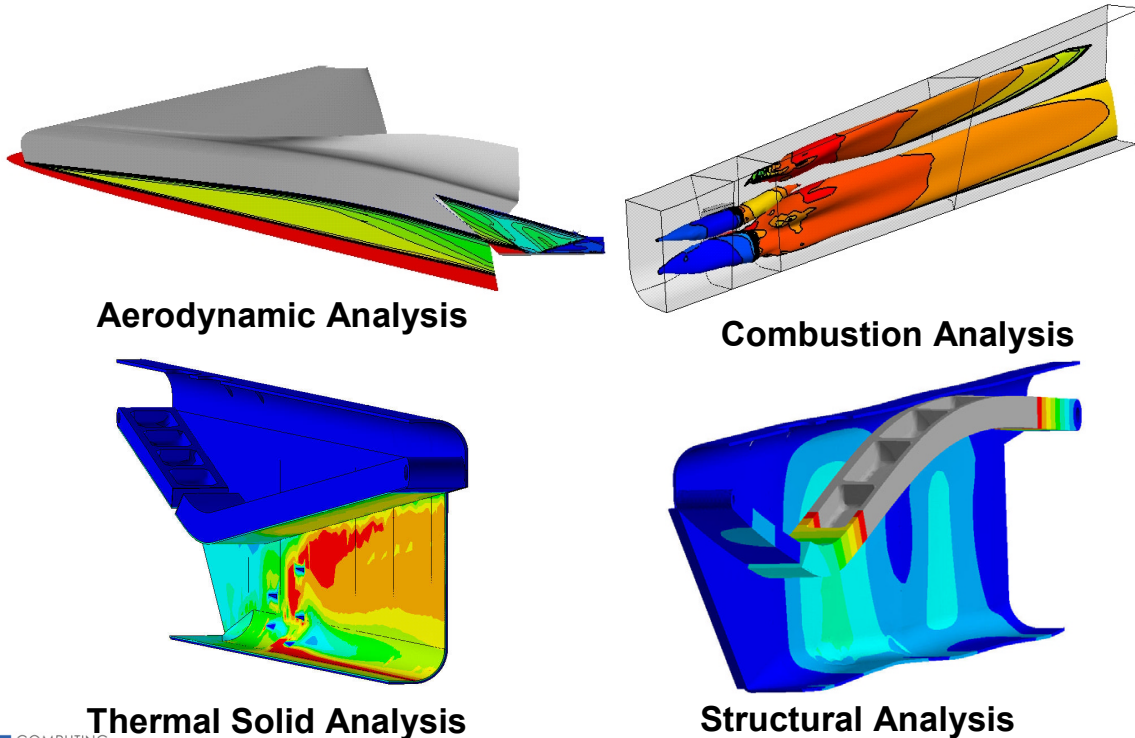
Outline

- **Overview & Motivation**
- **Description of Component Simulations**
- **Consistent Multidisciplinary Solutions**
- **Code Coupling Issues**
- **Benefits & Costs of MD Analysis**



2002 CISO Review

Multidisciplinary High Fidelity Analysis by Coupling Simulations



2002 CISO Review

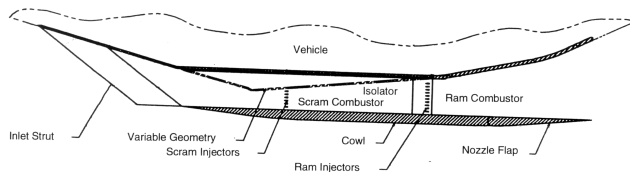
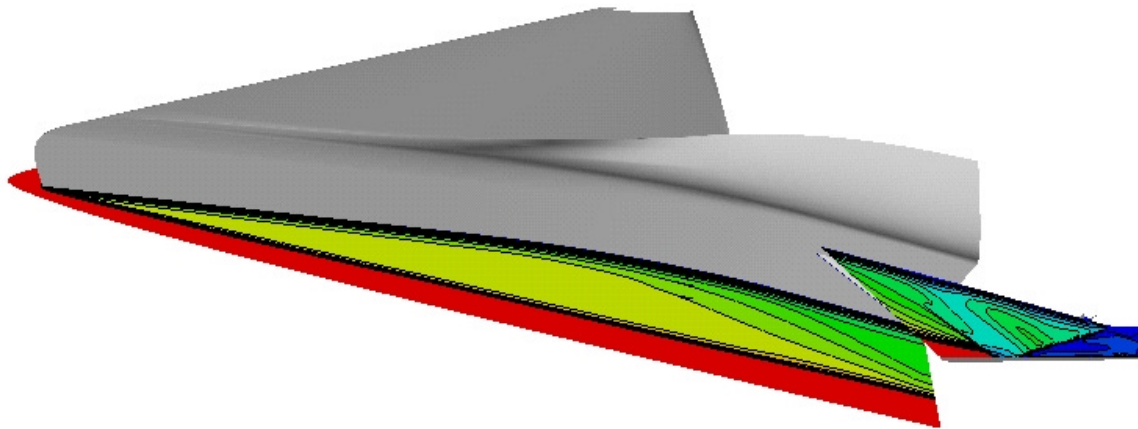
ISTAR Multidisciplinary Simulation: Objectives

- **Develop high fidelity tools that can influence ISTAR design**
- **In particular, tools for coupling Fluid-Thermal-Structural simulations**
- **RBCC/TBCC designers carefully balance aerodynamic, thermal, weight, & structural considerations; consistent multidisciplinary solutions reveal details (at modest cost)**
- **At Scram mode design point, simulations give details of inlet & combustor performance, thermal loads, structural deflections**



2002 CISO Review

Approach Flow: Mach Contours



2002 CISO Review

Approach Solution

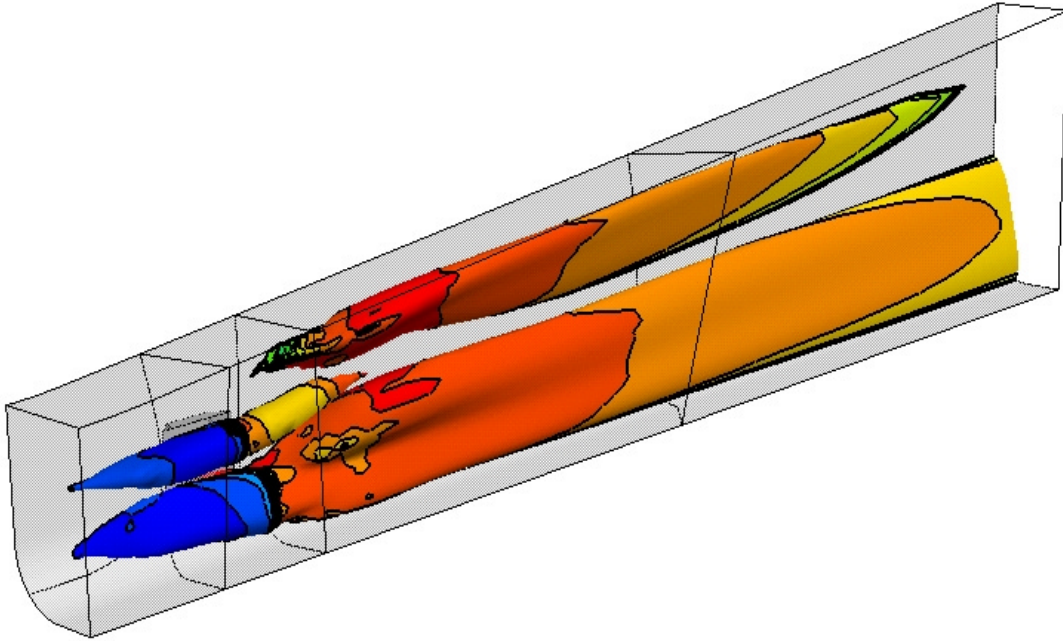
- Full Navier-Stokes solution using *Overflow*.
- Simulation includes forebody, canard, & engine inlet—only forebody geometry that influences engine inflow
- Chimera five block structured grid with 9×10^5 cells.
- $k-\omega$ turbulence model with low-Reynolds number form—no compressibility correction
- Equilibrium chemistry
- Sets Combustor inflow
- Yields heat & pressure loads for thermal & structural analysis



2002 CISO Review

Combustor Solution:

Fuel mass fraction iso-surface colored by temperature



2002 CISO Review

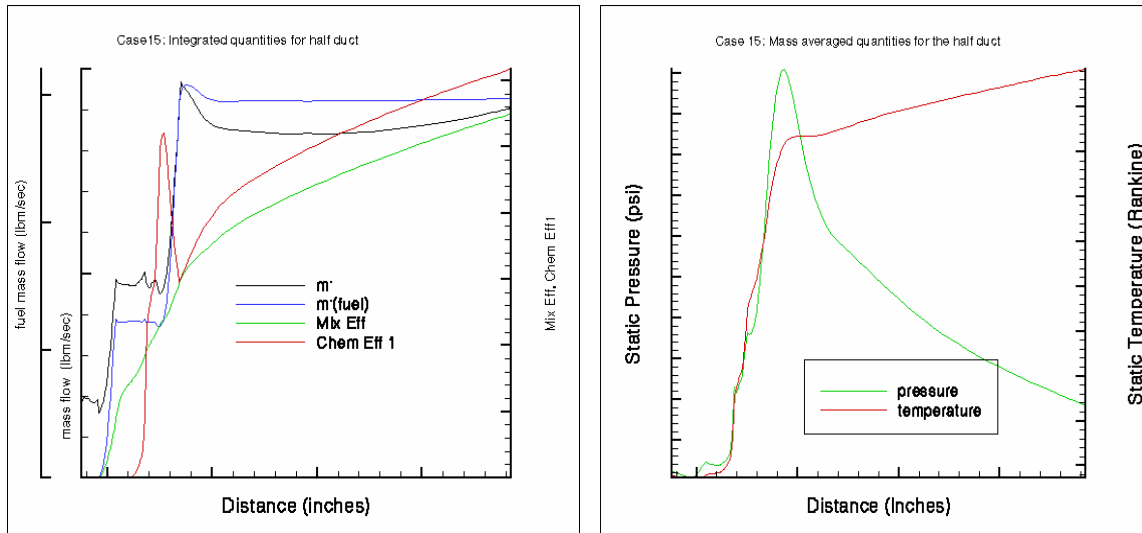
Combustor Solution

- Full Navier-Stokes plus finite-rate chemistry solution using *Vulcan*.
- Composite five block grid with 1.9×10^5 cells.
- 6-species 3-step finite-rate gaseous Ethylene model
- Inflow profile from Approach solution.
- $k-\omega$ turbulence model with wall functions; Compressibility correction
- Each injector modeled as a single triangular slot with equivalent area, massflow, and momentum. (normal injection).
- Flame holding cavity included.
- Yields heat & pressure loads for thermal & structural analysis



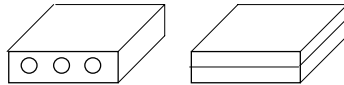
2002 CISO Review

Combustor Solution: 1-D Averaged Quantities



Thermal and Structural Solutions

- **ANSYS**—commercial finite element solver.
- 3-D unstructured grid with 1.3×10^5 nodes and 8.6×10^4 tetrahedra
- Temperature dependent material properties for Inconel 625, Titanium β 21S
- Coolant passages modeled as a bi-layer material



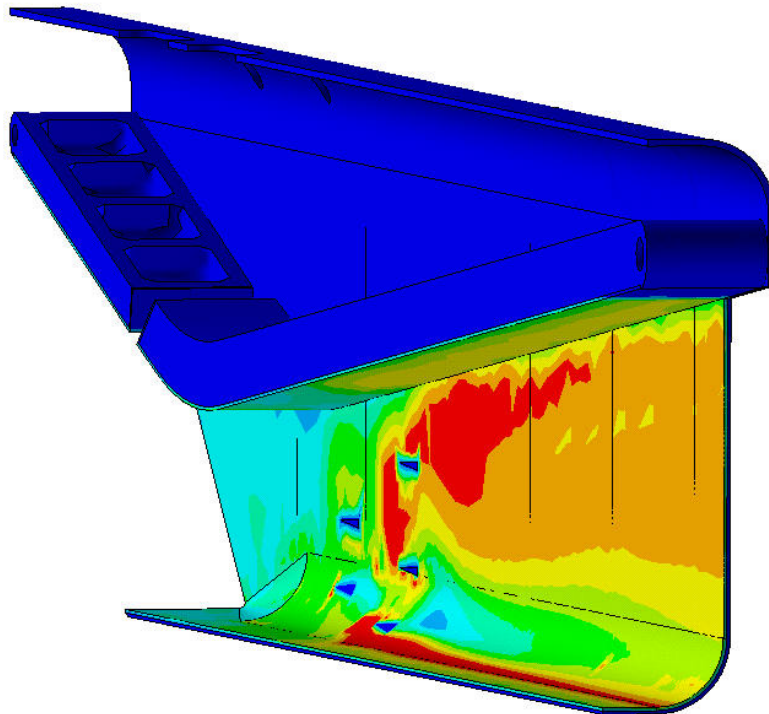
- Neglects details of heat conduction around coolant passages, plus structural effects
- Some modeling of coolant circuit.
- Thermal model yields temperatures from heat loads, coolant system, and material properties
- Structural model yields deflections & stresses from pressure & temperature loads

Ansys Thermal/Structural Grid



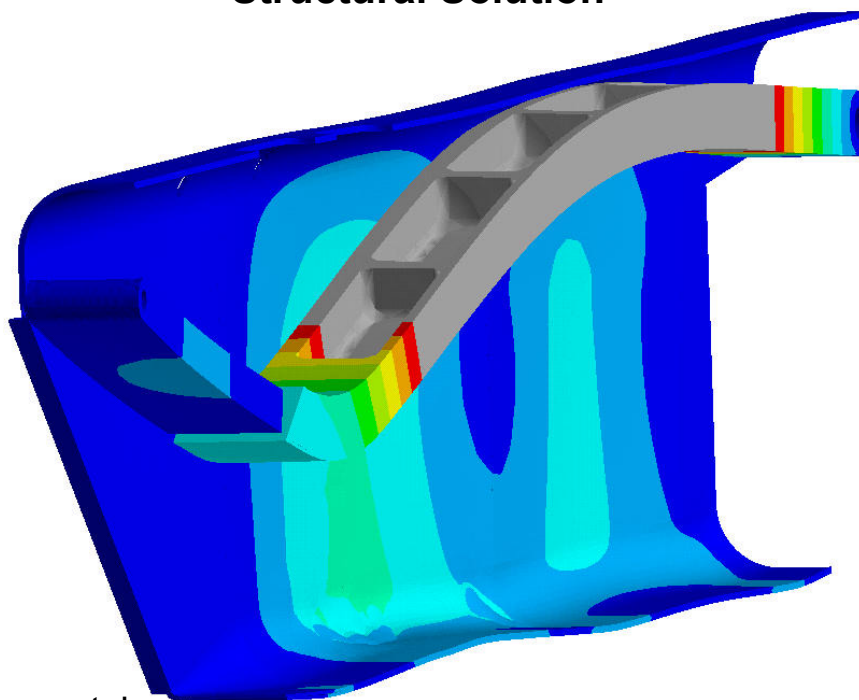
2002 CISO Review

Coupled Thermal Solution



2002 CISO Review

Structural Solution

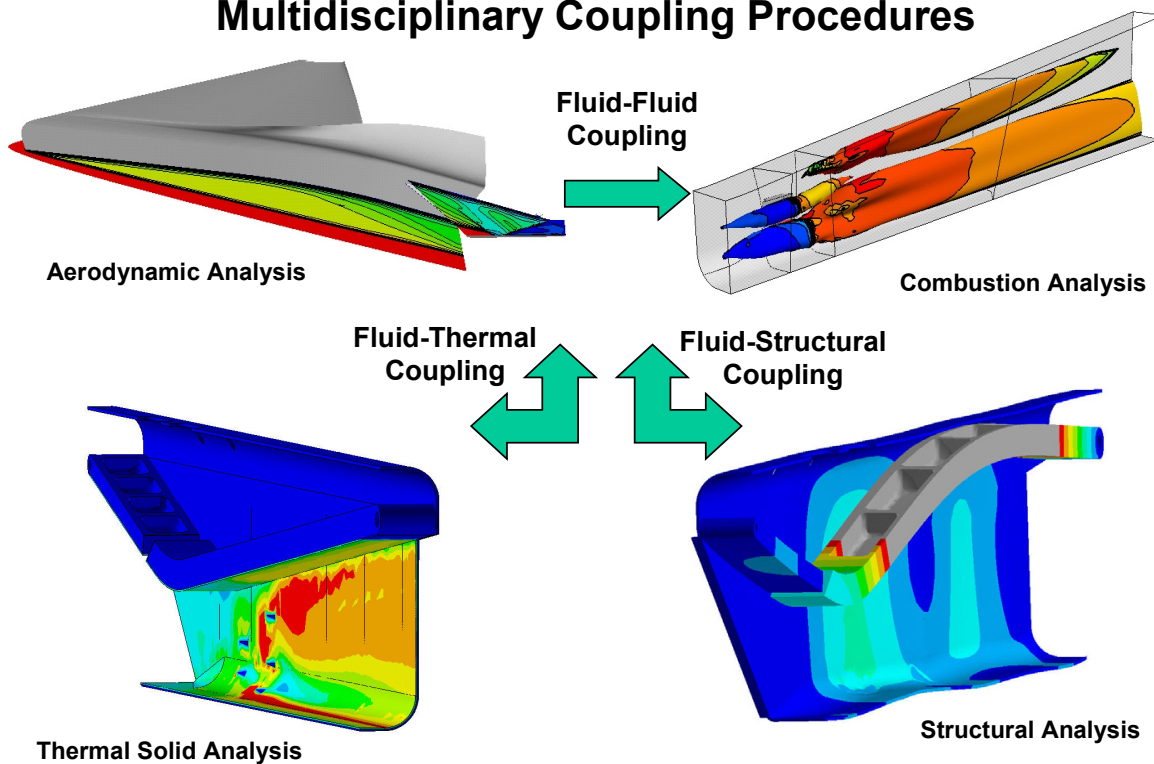


Deflections Exaggerated



2002 CISO Review

Multidisciplinary Coupling Procedures



2002 CISO Review

Consistent Multidisciplinary Solutions

- **Fluid-Fluid Coupling:** Flow quantities are the same where the Fluid codes meet
- **Fluid-Thermal Coupling:** Heat fluxes & Temperatures are the same where Fluid & Thermal codes meet
- **Fluid-Structural Coupling:** Deflected walls are the same as the Fluid boundaries



2002 CISO Review

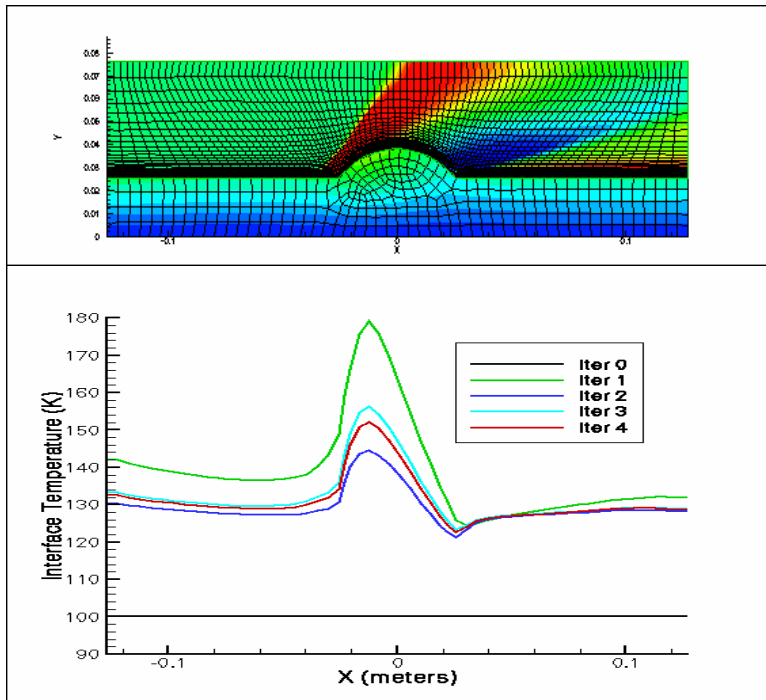
ISTAR Multidisciplinary Simulation: Interpolation & Consistency

- Interpolation transfers inflow profiles, thermal & pressure loads, displacements from code-to-code.
- One-pass:
(Fluid \Rightarrow Thermal \Rightarrow Structural)
Boundary conditions often inconsistent.
- Consistency achieved with multiple passes:
(Fluid \Leftrightarrow Thermal \Leftrightarrow Structural)



2002 CISO Review

Fluid-Thermal Iteration



In engine case,
L2 Norm of:

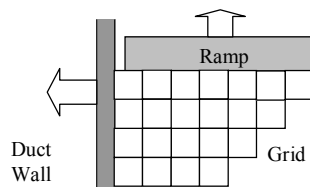
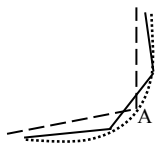
$$\Delta T = 500 \text{ }^{\circ}\text{R.}$$



2002 CISO Review

Challenging Issues in Coupling: Toolkit Specific

- **Robust interpolation between codes on wetted surface**
 - Accept all types of grids and formats.
 - Some tolerance for out of plane target points.
 - Subsetting of source grids.
 - Extrapolation at boundaries.



- **Update fluid grids to include surface deflections**
 - Difficult when deformations, particularly shear deformations, exceed the grid spacing.

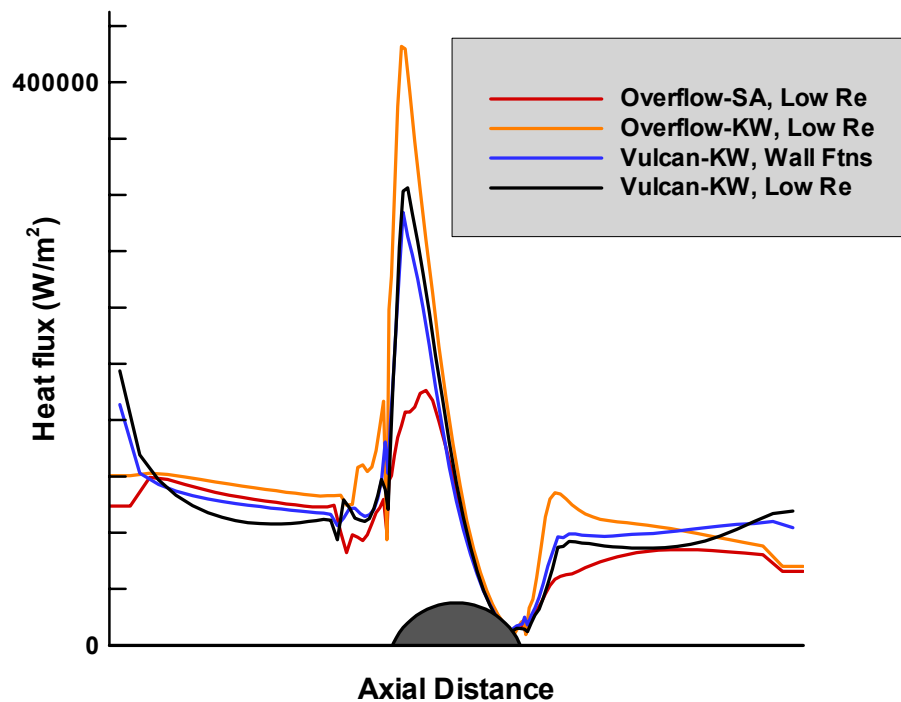


2002 CISO Review

Challenging Issues in Coupling: Code Specific

- Noisy heat fluxes from fluid codes
- Code compatibility w.r.t coupling (turbulence models, wall functions?)

Calculation of Accurate Heat Fluxes



Benefits & Costs

(Single Discipline vs. Multidisciplinary)

- **Cooling system design potentially aided by thermal/fluid calc.**
- **Computational cost: MD adds 100% of single discipline**
- **Cost of Setting up MD problem: a toolkit would help (Interpolation++)**
- **Disparate turn around times:
thermal & structural time is <1% of fluid & combustion**



2002 CISO Review

Summary

- **Single discipline simulations coupled into Multidisciplinary simulation.**
- **Application is Scram design point of ISTAR concept vehicle**
- **Reveal some code coupling issues and obstacles, costs and benefits**



2002 CISO Review